

# **Capturing Uncertainty in the Common Tactical/Environmental Picture: Team Summary and APL-UW Contributions**

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Award Number: N00014-00-G-0450-02

## **LONG-TERM GOALS**

The primary objective of the proposed effort is to use existing science to characterize and represent the uncertainty in the tactical and environmental picture due to uncertainty about environmental features that affect active acoustic detection of submarines.

## **OBJECTIVES**

The objectives of this project for FY02 were (1) to model reverberation data for an actual geographic location and sonar system for which real data exists that incorporates the effects of background internal waves, range-dependent bathymetry, and representations of sea floor/sub-floor geoacoustic conditions derived from various sources, and (2) coordinate a team, comprised of scientists from six different institutions, including APL-UW, in the investigation of several related questions focused on characterizing and representing undersea environmental uncertainty. Scientists from the three other institutions are submitting independent reports referenced in paragraphs below. This paper combines an overview of their efforts with the accomplishments of APL-UW, NRL-SSC, and NRL-DC. Specific questions being explored by this project are: 1) how can we merge uncertainty in large-scale sound speed fields with the uncertainty created by internal waves to generate a distribution of sound speed profiles, 2) what is the value of a dynamic model versus a statistical approach, 3) what is the contribution of internal waves to uncertainty and how many modes are needed, 4) how can we characterize uncertainty in the ocean bottom sediments either through historical data or acoustic inversion techniques that can be used to generate a distribution of local bottom conditions, 5) given uncertainty of the ocean sound speed and the bottom, can we develop techniques to efficiently propagate the uncertainty through active acoustic models to components (e.g., transmission loss, arrival structure, interference) that can be used for tactically relevant (i.e., real-time) state estimation of undersea targets, and 6) can we improve the state estimation of targets (e.g., position, speed, and classification) through the knowledge of environmental uncertainty?

While it is desirable to include other environmental components such as surface boundary impacts, volume reverberation, bathymetry, and ambient noise, the framework developed through investigation of water column and bottom contributions to the underwater acoustical uncertainty problem should accommodate these affects in the future.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>30 SEP 2003</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2003 to 00-00-2003</b>	
4. TITLE AND SUBTITLE <b>Capturing Uncertainty in the Common Tactical/Environmental Picture: Team Summary and APL-UW Contributions</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Applied Physics Laboratory,,University of Washington,1013 NE 40th Street,,Seattle,,WA, 98105</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <b>The primary objective of the proposed effort is to use existing science to characterize and represent the uncertainty in the tactical and environmental picture due to uncertainty about environmental features that affect active acoustic detection of submarines.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>6</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## **APPROACH**

Work is being accomplished by a team headed by APL/UW that includes NRL-SSC, Oregon State University (OSU), ARL-UT, and Metron Corp., all funded under the ONR Capturing Uncertainty Departmental Research Initiative (DRI). NRL-DC is contributing valuable work as well, funded by ONR outside the DRI.

NRL-SSC is providing the best ground truth sound speed profile and geo-acoustic data possible for the geographic area selected for analysis. It is also investigating the feasibility of incorporating dynamic ocean modeling as a foundation for MODAS to generate more accurate three-dimensional sound speed profile predictions. This more accurate sound speed profile representation will be compared with a statistical approach to dealing with range and time dependent uncertainty of water column conditions. OSU and APL-UW are collaboratively producing sets of time-dependent two-dimensional sound speed profiles using an internal wave model fed by different input seed sound speed profiles. These profiles are then fed to the Comprehensive Acoustic System Simulation (CASS), run by APL-UW, along with selected bottom geoacoustic descriptions, to produce reverberation time series. ARL-UT is applying signal processing and statistical analysis to the time series, and recasting them as likelihood function distributions of target state, a form suitable for implementation in a Bayesian Likelihood Ratio Tracker (LRT). Metron is assisting with this translation of the environmental data into likelihood functions and is responsible for LRT development. Target state estimates arising from the LRT will reflect the input environmental uncertainty. Hence, by varying input environmental parameters in known ways, the effect on sonar performance and detection capability can be studied. Initially, our focus will be on the effects of background internal waves and bottom backscatter and reflection loss on monostatic active sonar returns. NRL-DC is developing ways to cast target and environmental state estimations from the LRT in graphical form to provide visual representations of target and environmental uncertainty suitable for fleet operators. A related APL-UW task involves the coding of Frechet derivatives used to assess the sensitivity of the effect on water column acoustic pressure to changes in sediment bulk modulus and density.

## **WORK COMPLETED**

For the initial phase of the project, we chose a time and region of the world to begin modeling that corresponds to a representative tactical exercise. This exercise took place in the East China Sea during July and August of 2000 in an area just west of the Ryukyu Trench. This site was chosen both for its tactical relevance, reasonably uniform geo-acoustic environment, and the availability of active sonar data. A particular event that took place during the exercise, involving a diving and resurfacing submarine, that provides an especially useful collection of continuous wave (CW) and wide-band acoustic data. This will be used as the starting point for our investigations.

NRL-SSC provided detailed descriptions of the geo-acoustic conditions of the sea floor/sub-floor based on interpretations of a compilation of grab and core sample data taken over many years in the geographic region of interest in the East China Sea. NRL-SSC has also provided MODAS and measured sound speed profiles for the area along with the range of expected values for that location and time of year. These were used as initialization seeds for internal wave model run by OSU. NRL-SSC is also considering the investigation of use of a full ocean circulation model to drive MODAS.

Several estimates of acoustic sound speed fluctuations due to background internal waves as a function of depth, range and time, were collaboratively developed between OSU and APL-UW for CASS input.

To begin the exploration of the sensitivity of the acoustics to the internal wave field, different realizations of the internal wave field were generated with varying amplitude of the background internal waves, depths of the top and bottom mixed layers, and homogeneity of the mixed layers. As an example, measured, Levitus climatology, and MODAS-predicted sound speed profiles were used as seeds for the internal wave model. APL-UW incorporated this input sound speed data into the CASS model along with bottom geo-acoustic data.

In addition to the internal wave and profile variability, the coherence of the internal wave model itself was explored by taking sets of data both 18 seconds apart and 3000 seconds apart from the model for the same starting point. Noticeable coherence appeared between the CASS reverberation time series with realizations taken at 18 second intervals. Realizations taken at 3000 second intervals are independent.

Both narrow (long CW) and wide band (short pulse) sonar signals were modeled in CASS. Both incoherent and coherent reverberation time series were produced. At the time of publication, there remained in both time series an inexplicable artifact, seen in the wideband example at figure (1) that appears as a periodic null, predominantly in the surface reverberation contribution, and gives the series an un-physical appearance. The reason for the artifact isn't known yet, but the developer of CASS is assisting APL-UW with the investigation. The artifact contaminates the statistical properties of the time series examined by ARL-UT and must be resolved.

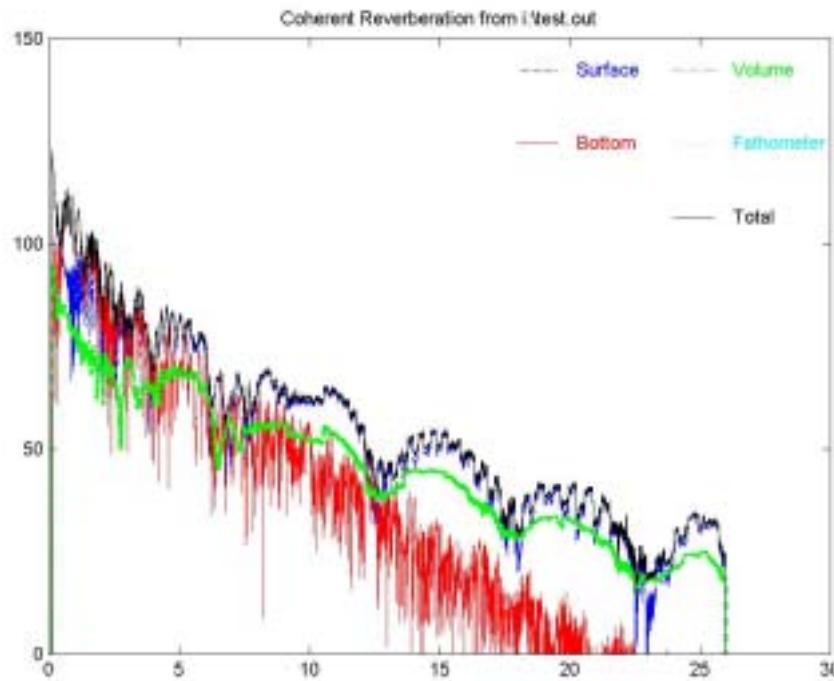
APL-UW compared CASS-modeled transmission loss with RAM-modeled transmission loss as a benchmark using input parameters representative of the geographic area of interest. Several iterations were required.

APL-UW fostered collaboration between team members by organizing a two-day conference at Stennis Space Center in March 2002 and a day-long meeting in advance of the Uncertainty DRI conference held in June 2002. Crucial activities and commitments between the distributed partners of this task are administered to keep the team moving forward.

Frechet derivatives can be used to evaluate the sensitivity of sediment effects on acoustic pressure as a function of perturbations in the bulk modulus or density of the sediment. APL-UW coded these derivatives and computed them for a representative bottom sediment model for the East China Sea provided by NAVOCEANO. The relationships between these basic derivatives and sensitivities to other quantities of interest, e.g. sound speed and attenuation have also been derived. Analytical expressions for derivatives exist and are simple functions of the depth-dependent Green's function. APL-UW modified the wavenumber integration program OASES (Schmidt, 1988) to compute the derivatives.

For the Bayesian tracker ARL-UT and Metron have developed two likelihood descriptions for characterizing uncertainty at both the signal and information processing level of an active monostatic sonar. The first is a cluster-based likelihood function that was developed using as its measured input the mean position of threshold crossings in a cluster and the number of such clusters, as determined by the Echo Tracker Classifier (ETC) automated active sonar system. The second is a measurement log-likelihood ratio (LLR) function based on beamformer output and independent model predictions of mean reverberation. Preliminary comparisons made by ARL/UT suggest the LLR may provide a higher signal-to-noise ratio compared to the standard normalizer used in ETC. ARL-UT also made some preliminary statistical comparisons of CASS-predicted reverberation, including internal wave

effects, to actual reverberation measurements made at sea. Metron has worked with NRL-DC to develop methods of displaying the uncertainty in the target state estimates produced by a Bayesian tracker such as Nodestar or LRT.



***Figure (1) Coherently modeled reverberation time series from CASS for a 0.005 millisecond 3.5Khz pulse and a 1.5 meter range increment.***

## RESULTS

OSU and APL-UW have worked together to produce numerous background internal wave statistical realizations for several different cases that are being used in CASS modeling runs. For now, this work is complete. APL-UW has discovered a CASS output artifact affecting coherent narrow and wide band reverberation time series and is seeking system expert assistance to resolve the issue. If CASS cannot model statistically reasonable coherent time series, the team will need to develop an alternative. ARL-UT has obtained reasonable predictions of reverberation levels for the region of interest in the East China Sea from an idealized CASS-modeled time series. Preliminary results suggest that the impact of variations in the sound speed field due to internal waves contributes a standard deviation in the predicted reverberation levels on the order of 2 dB. Further work is contingent on resolving the modeling artifact seen in the most recent CASS-generated time series. Metron has established an approach for applying Likelihood Ratio Tracking to active monostatic sonar. The next step is to incorporate and represent environmental uncertainty in the likelihood functions and the resulting state estimates. NRL-DC has produced several graphical examples of how uncertainty can be represented and has engaged Metron and ARL-UT in discussions on how statistical target and environmental state estimation data can be used to produce such representations.

Frechet derivative computations made by APL-UW show that for data acquired at low grazing angles, perturbations in sediment density and bulk modulus have opposite signs on the measured pressure in the water column, and thus can be distinguished. At large grazing angles near normal incidence, derivatives for density and bulk modulus have the same sign and magnitude, which means that information about density and velocity perturbations cannot be independently resolved from data comprising steeply arriving rays.

## **IMPACT/APPLICATIONS**

Results of the team's work will apply to numerous Navy acquisition programs. Virtually all Navy Tactical Decision aids used in air, submarine, and surface ASW and MCM communities will, in time, be modified to include methods developed from this program to quantify and represent to fleet operators the uncertainty of estimations of sensor performance. Results of the program will improve the ability of Navy personnel, from sonar system operators to battlegroup staff commanders, to understand how well their systems are working and how best to employ them. These results will similarly be used to provide environmental sampling recommendations to reduce uncertainty in critical parts of the battle space.

## **TRANSITIONS**

SIIP, STDA (surface and submarine), TAMDA, SPPFS, MEDAL, CUP, TDA IV&V

## **RELATED PROJECTS**

1. APL-UW is contracted with NAVAIR (PMA264) to assist with the **EER Improvement Program**.